LA-UR-14-21366
Approved for public release; distribution is unlimited.

Title: Renewable Energy: science, politics, and economics

Author(s): Migliori, Albert

Intended for: Colloquium at University of Florida 20 Feb 2014

Issued: 2014-03-03

Renewable Energy: science, politics, and economics

Albert Migliori
Fellow, Los Alamos National Laboratory

Providing adequate energy and water while preserving a sustainable global environment may be the single most important problem ever to face humanity.

Maybe that's why we're here?

Arghhhh. What a mess.

- The changes coming in how we generate, capture, store, and deliver energy to modern civilization are so complex that it will take all that modern civilization has to navigate through them.
- As technical solutions emerge, are tested, and then discarded or retained, our economic subsystem must be deliberately and rationally distorted to give that technology breathing room to develop.
- Laws, rules, and regulations must be the primary vehicle for providing the necessary safety net and the economic distortions to enable implementation of new science, technology, and engineering.

Los Alamos NATIONAL LABORATORY EST.1943

The world is not the same as it was in 2008

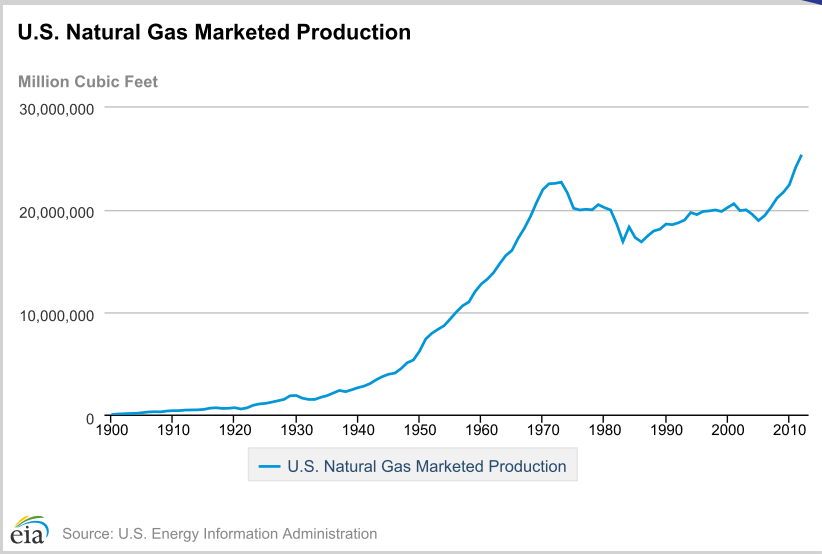
- Natural gas-the price plummeted in recent years-or did it?
- Coal -EPA New Source Performance Standard (NSPS) limit CO_2 to 1000 lbs per MW-hr. None of the existing coal plants meet this standard.
- Fukushima-Tepco has been heavily criticized for its inept response to the 2011 disaster at Fukushima, including delays in releasing radiation data. Public perceptions deeply affected. Rightly?
- 400PPM-For the first time in recorded history, atmospheric CO_2 crossed the 400 PPM barrier.
- Denmark-Exceeds its total energy consumption with wind energy. But only by stressing the EU grid. Unsustainable but apparently cost competitive.
- Drought-California drought reaches new level of severity never recorded on U.S. drought monitor in the state.
- Photovoltaics-below $1.00/W.

Los Alamos NATIONAL LABORATORY EST.1943

Natural gas is plentiful because of "fracking" and much cleaner than coal

Pounds of CO_2 emitted per million Btu of energy for various fuels:

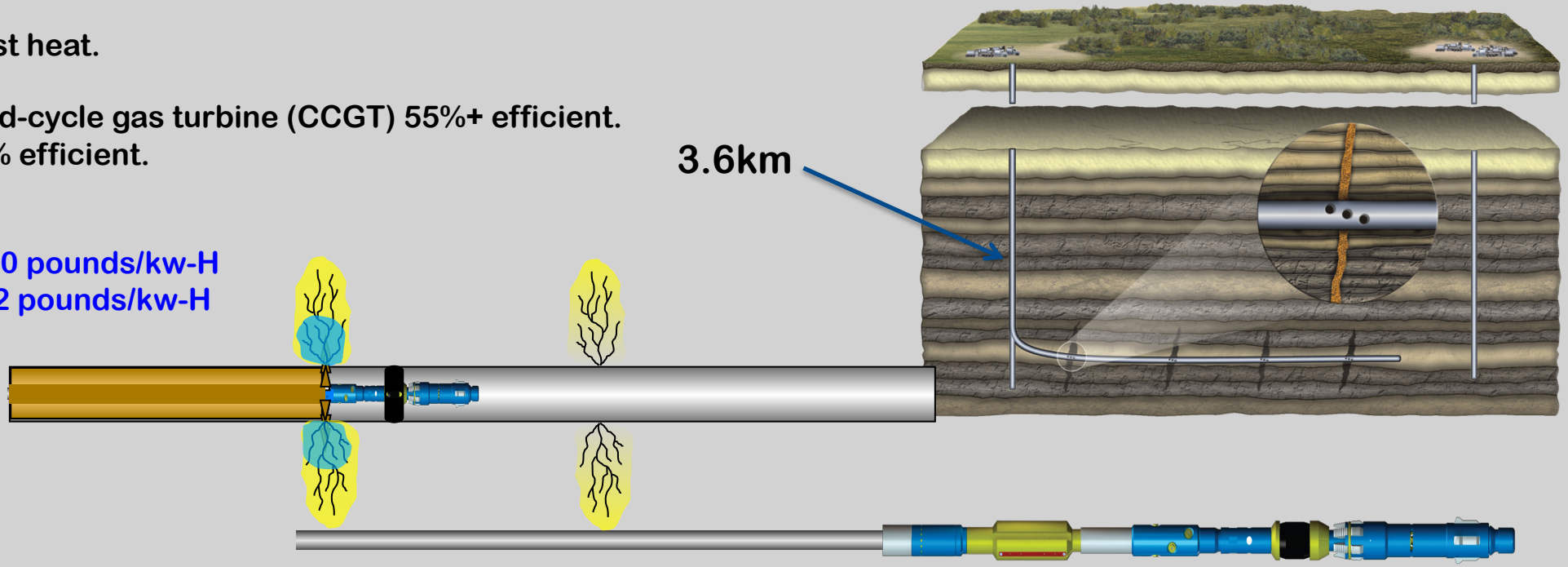
Coal (anthracite)	228.6
Diesel fuel & heating oil	161.3
Gasoline	157.2
Propane	139.0
Natural gas	117.0



That's just heat.

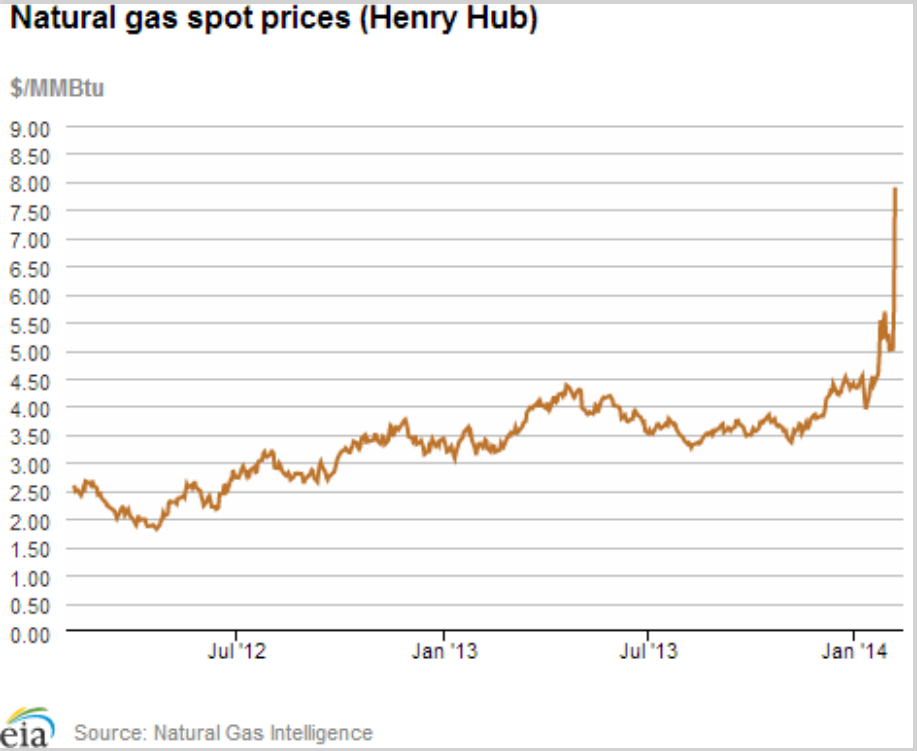
Combined-cycle gas turbine (CCGT) 55%+ efficient.
Coal 33% efficient.

Net CO_2:
Coal—690 pounds/kw-H
Gas—212 pounds/kw-H



Los Alamos NATIONAL LABORATORY EST.1943

Natural gas is the short-term clean solution. But…



The 262 billion cubic foot (Bcf) withdrawal from storage reported today placed gas storage levels falling below the 5-year range.

Cold weather has driven record-high cumulative withdrawals.

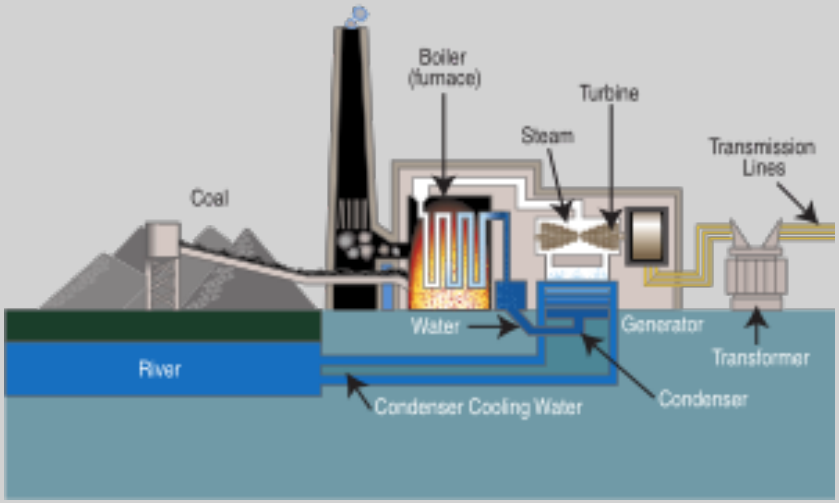
Natural gas drives complacency against renewable energy innovation.

And the price?

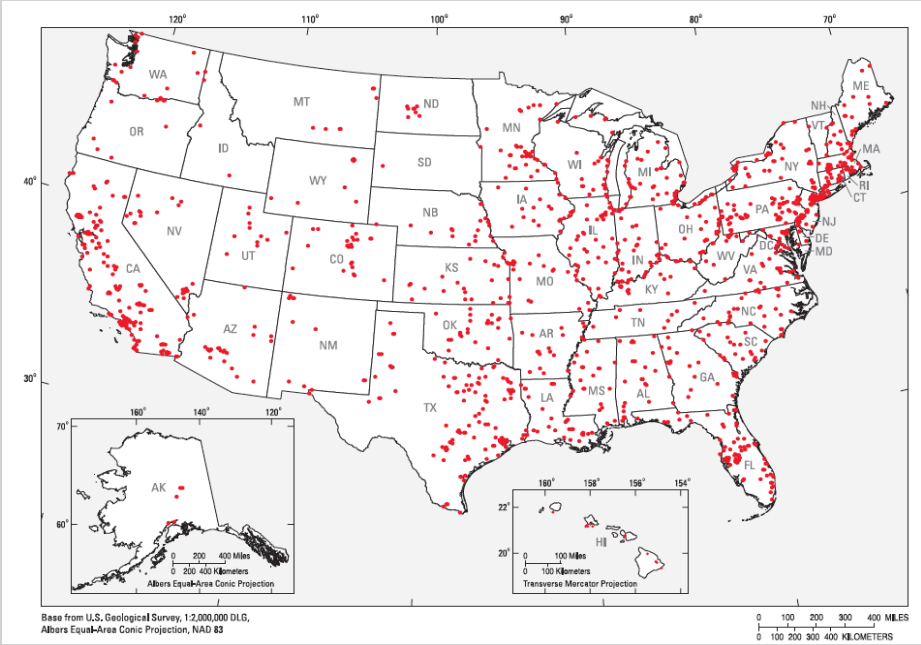
And the environment?

Los Alamos NATIONAL LABORATORY EST.1943

Coal, water, inextricably linked



Geographic distribution of the 1284 thermoelectric power plants with water cooling systems in the US.

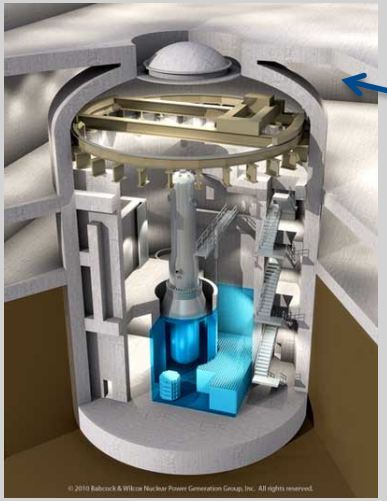


Unlikely that any new coal generation will be licensed in the US because of the EPA New Source Performance Standard.

Finally. Gov't drives change here.

A surprise relating to nuclear energy-and legislative opportunities

It is estimated that during 1982, US coal burning released 155 times as much uncontrolled radioactivity into the atmosphere as the Three Mile Island "incident" [sic].



4 years, 2 steps to license.

2 years, single step to license

Gov't—fix this.

50 MW to 300 MW Small Modular Reactor. Even safer—mass produced at plant, transported to site.

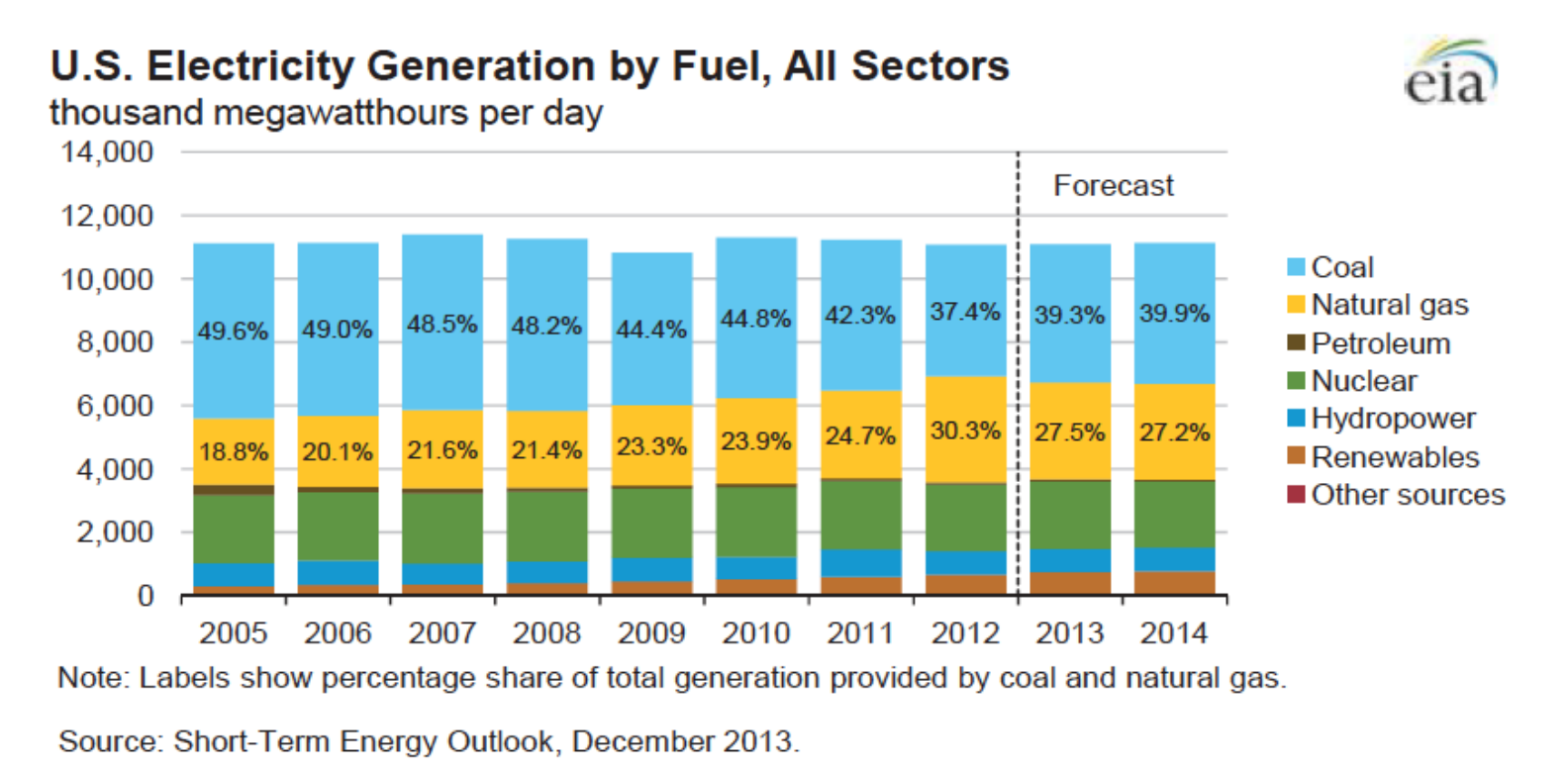
The ***AP1000*** meets the U.S. NRC deterministic-safety and probabilistic-risk criteria with a very low core damage frequency (CDF) that is 1/100 of currently operating plants and 1/20 of the maximum CDF deemed acceptable???.

New materials science heading toward more stable fuels—rad damage, swelling and more under research.

Nuclear energy should not be discounted-zero emissions

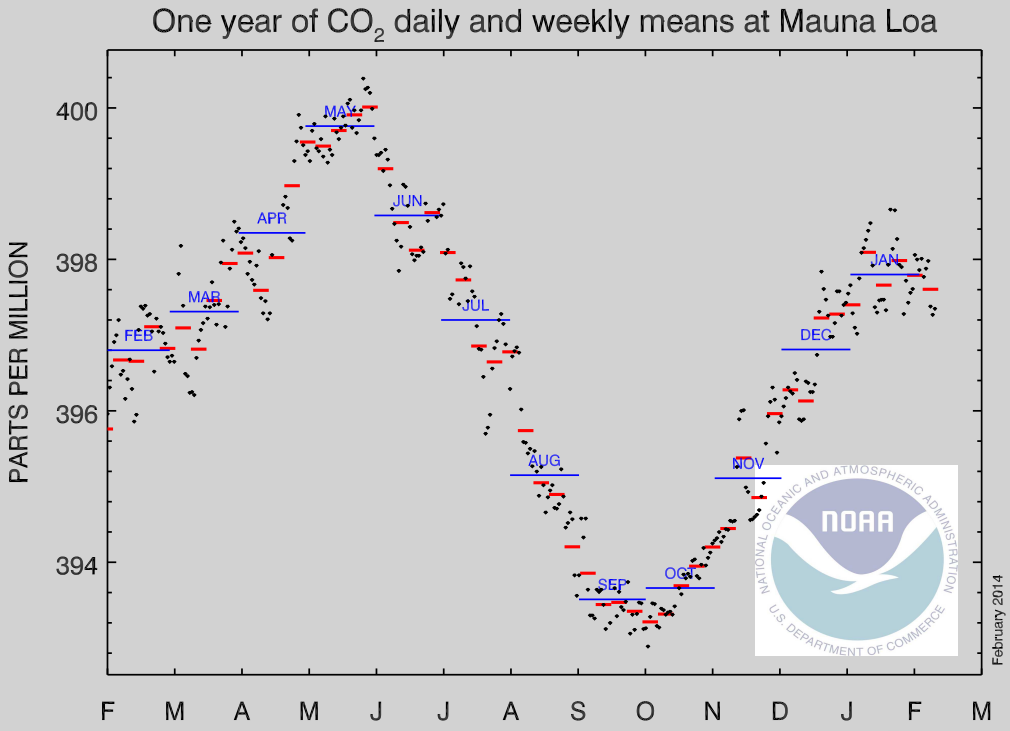
The US doesn't license fast breeder reactors to recycle fuel because we have huge reserves of uranium and plenty of room to store waste.

For now.



Los Alamos NATIONAL LABORATORY EST.1943

CO_2 out of control in 2013



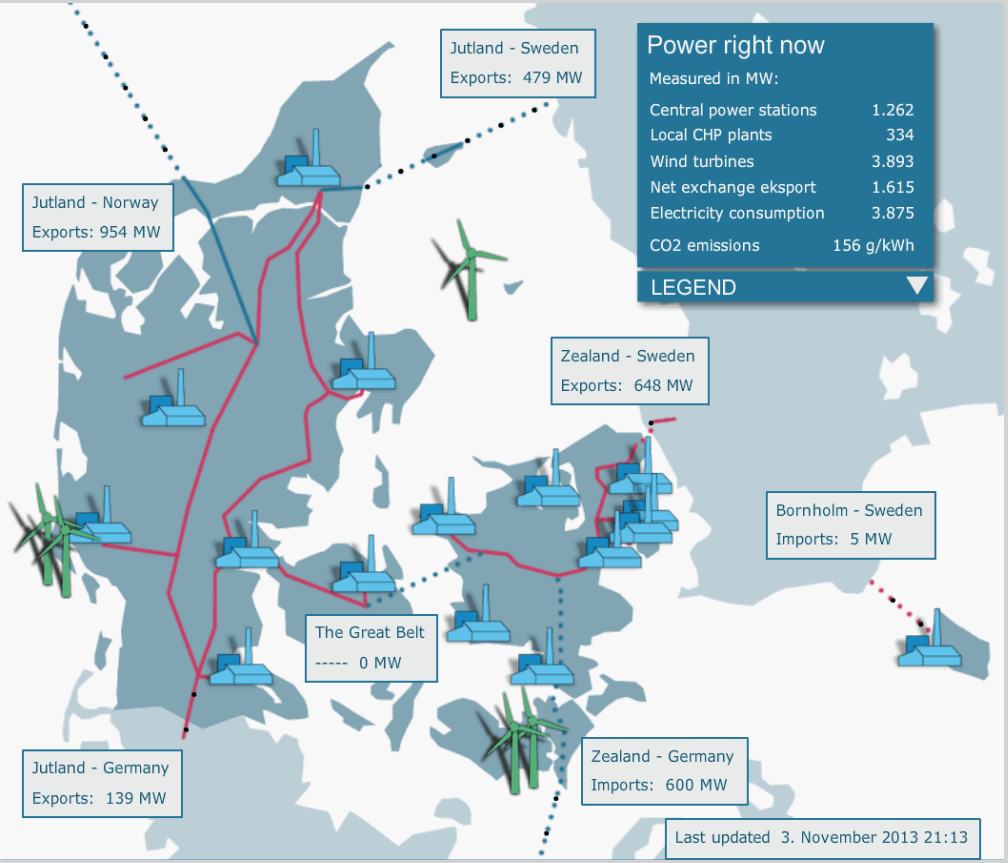
February 2014

If we melt the global ice caps

you are here

Los Alamos NATIONAL LABORATORY EST.1943

Denmark and Germany—parasitic renewable generation?



Denmark makes more wind energy than its electricity consumption. Germany plagues neighbors by dumping unpredictable surges of wind and solar power.

Pesky physical law-conservation of energy.

So they export to the EU grid.

This is neither sustainable, nor expandable. If the whole EU did this, then the system fails because there is no place to put energy.

Energy storage and grid math required, Gov't must intervene.

Los Alamos NATIONAL LABORATORY EST.1943

Wind technology opportunities

Cost reductions from the increasing share of gearless drive generators using permanent magnet synchronous motors. Overall, cost reductions could reach 15% by 2020. materials science will lead the way.

Intelligent wind turbines, instrumentation, and design—transform current engineering practice with techniques to understand, identify, and manage turbine rotor damage.

Siting----big computers can use wind data, terrain maps, and turbine characteristics to site turbines in a farm so that they do not interfere with each other to increase annual output by 10% give or take.

Bearing failure-wild loads out of the design envelope generate bearing failure-big mechanical engineering problem.

Energy Security Council

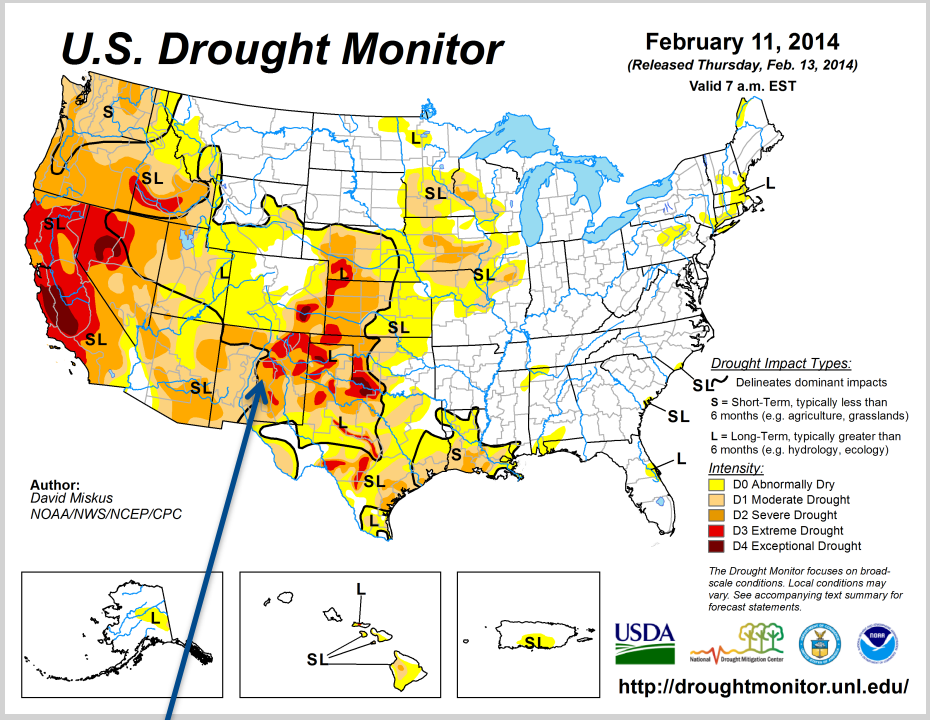
Los Alamos NATIONAL LABORATORY EST.1943

I lost trees last year that survived the great dust bowl of the 1930's

POLITICS AND POLICY WSJ

Battle Over California Drought Solution

As Golden State's Fields Grow More Parched, Washington Offers Dueling Remedies



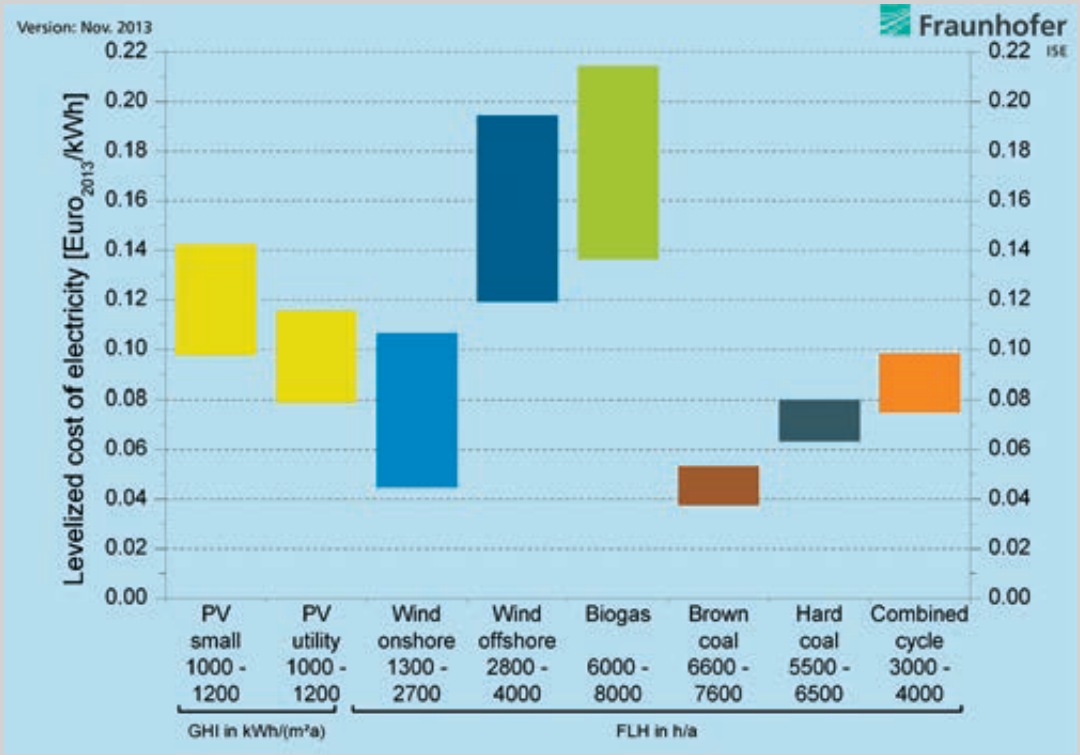
Bizarre legacy water rights legislation utterly trashes our ability to manage, and wrecks the economics. In Texas, there is no limit to how much ground water you can pump.

Shrimp farms in the desert?

I am here

Los Alamos NATIONAL LABORATORY EST.1943

Renewable energy is getting cheaper-let's think about this



LCOE-levelized cost of electricity is the price at which electricity must be generated from a specific source to break even over the lifetime of the project.

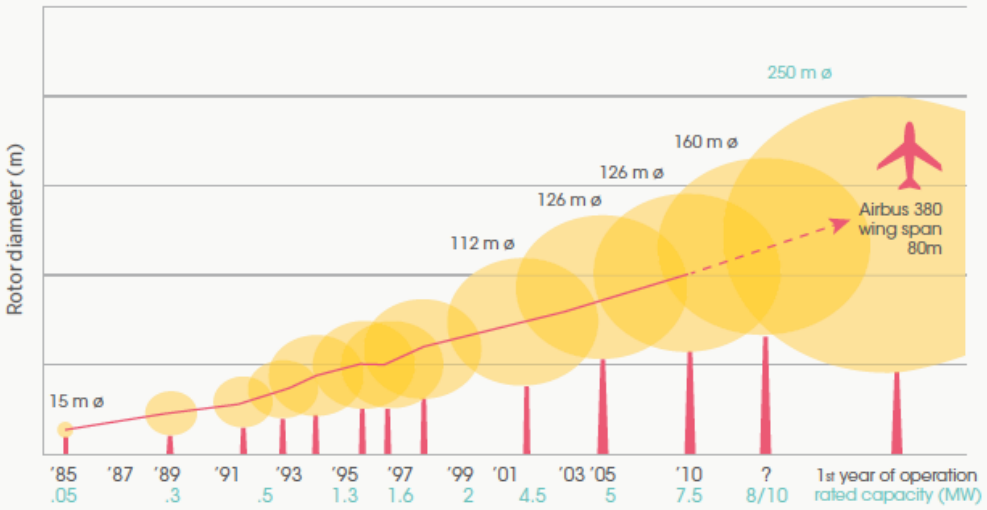
It is an economic assessment of the cost of the energy-generating system including all the costs over its lifetime: initial investment, operations and maintenance, cost of fuel, cost of capital.

Talk about an ill-posed math problem!

Costs are a mess—I don't much believe any of it.

Los Alamos NATIONAL LABORATORY EST.1943

An interesting limit



Gov't can wildly distort the LCOE. This has given the wind industry time to become efficient.

What if the cost of wind energy drops another 25% as is likely? The cheaper it is, the more idle turbines you can afford.

Today, capacity factors are like 17% in NM.

Gov't provides tax breaks on installed capacity, not output. This is a major economic distortion and leads to an effective surcharge for energy storage systems.

Wind had its chance—let's do the same for energy storage and grid technology.

Limiting case: wind turbines are free. Then you can build so many that even in the lightest of winds, you make all the electricity you need. Shut them down in high winds, no problem. Not gonna happen.

Gov't must now provide legislation to encourage energy storage and grid upgrades just as it did for wind.

Los Alamos NATIONAL LABORATORY EST.1943

So what do we do? A select set leaving out fossil fuel and nuclear.

Problem: How can we transition (slowly) to almost all renewable energy? Even if we don't get there, is life better on the way?

Background: We know how to make electricity from sunlight, wind, nuclear, fossil fuels, hydroelectricity.

Interfering effects: Politics and economics.

Strategy: a) Improve the resilience and responsiveness of the utility grid to renewable energy penetration. b) Provide grid-scale electrical energy storage.

Tools: Technology and legislation.

Los Alamos NATIONAL LABORATORY EST.1943

Accuracy of our ability to predict technology

"Television won't be able to hold on to any market....People will soon get tired of staring at a plywood box..." Darryl Zanuck, 20th Century Fox, 1946.

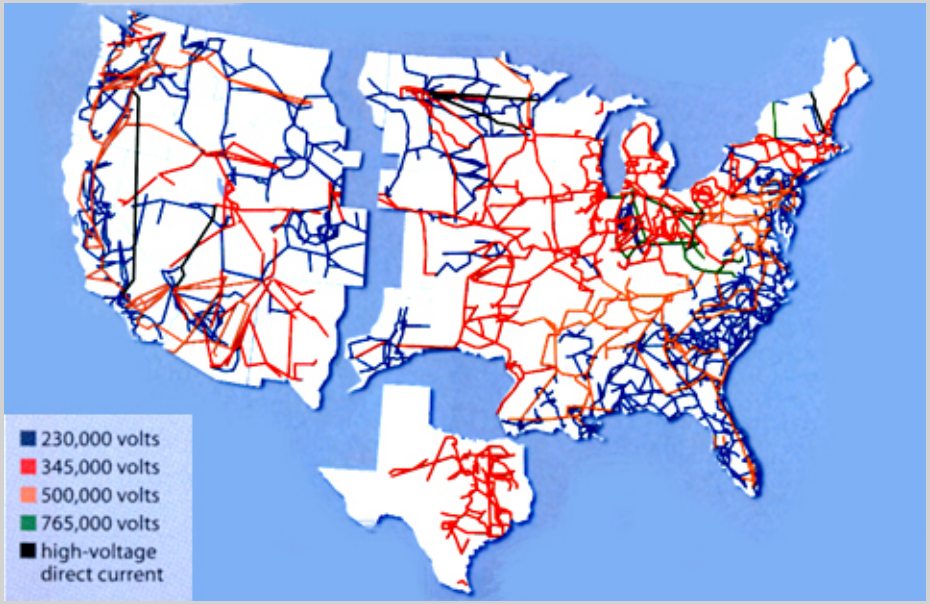
"There is no reason anyone would want a computer in their home," Ken Olsen, founder of mainframe-producer Digital Equipment Corp., 1977.

I said to my brother Orville that man would not fly for 50 years. - Wilbur Wright

"There's no chance that the iPhone is going to get any significant market share. No chance." -- Steve Ballmer, CEO of Microsoft

Los Alamos NATIONAL LABORATORY EST.1943

The utility grid is really obsolete



Legislation requires full nameplate capacity for transmission lines from a wind farm even if the farm never hits that output.

Speed of light effects make sure you cannot synchronize generation over a 2-D map the size of a grid.

There are only three grids in the US. West, East, and Texas.

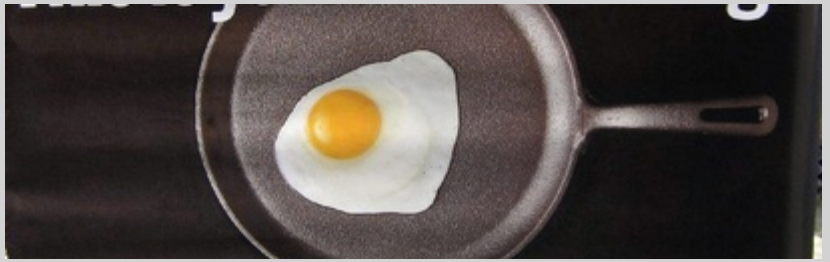
There's more…

Los Alamos NATIONAL LABORATORY EST.1943

Renewables trash the grid

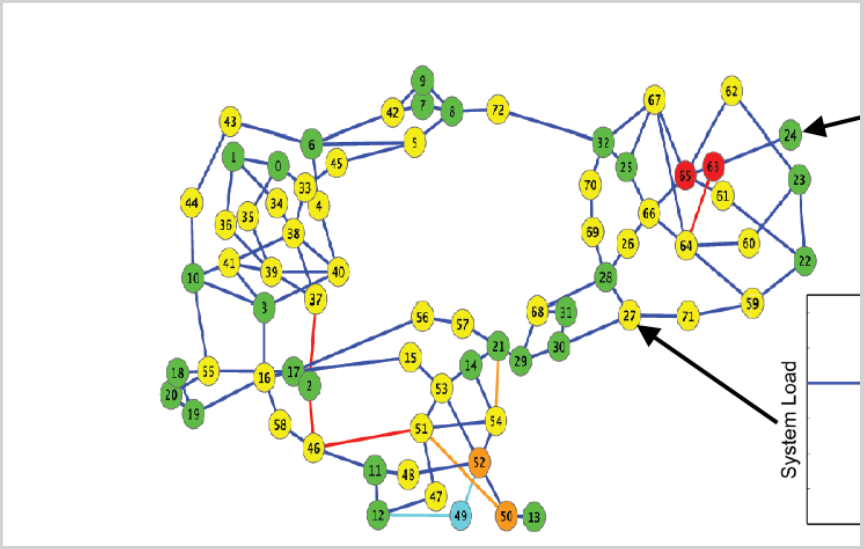
This is your utility grid:

- Loads are well forecasted
- Generation is controllable
- Network evolves slowly and predictably



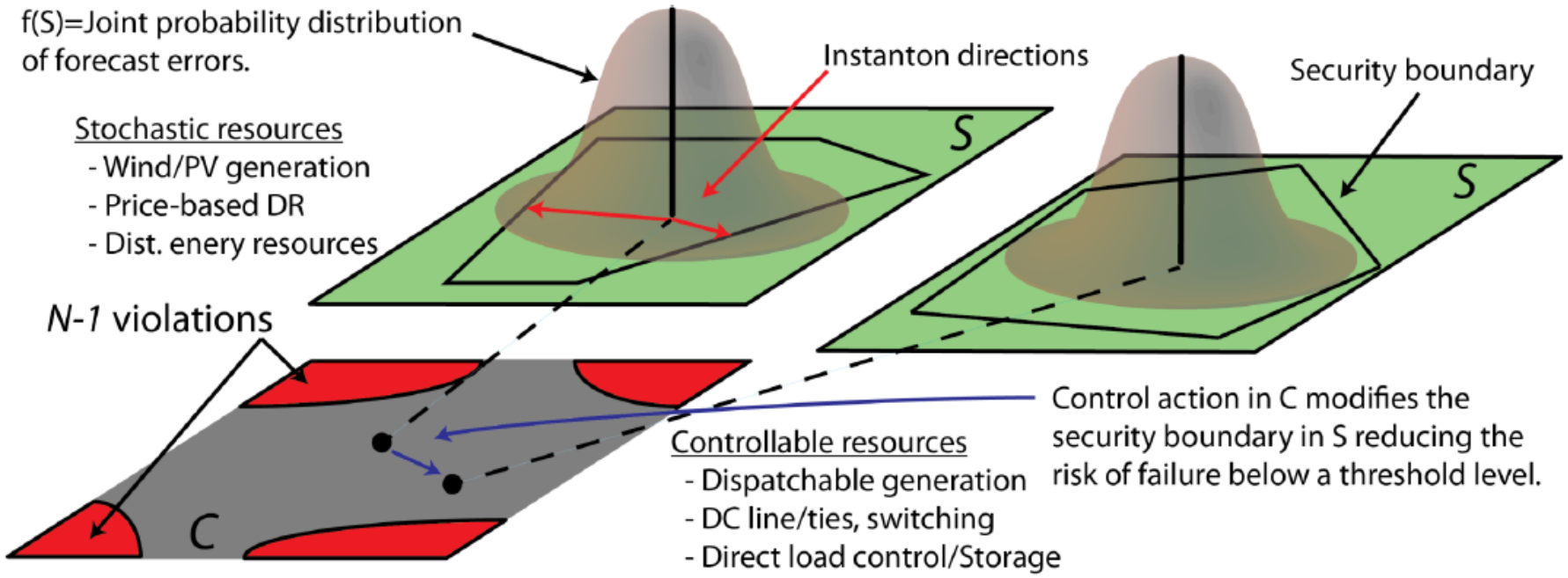
This is your utility grid on renewables:

- Generation becomes stochastic
- Fluctuating network flows—Network evolves quickly
- Coupling between time scales



Los Alamos NATIONAL LABORATORY EST.1943

The grid is a wild, ill-posed math problem



Some of the best mathematics is now being applied to the ultility grid.

If we can do good on modeling, we can tell gov't and economics where to go.

Los Alamos NATIONAL LABORATORY EST.1943

Nothing is simple or separable

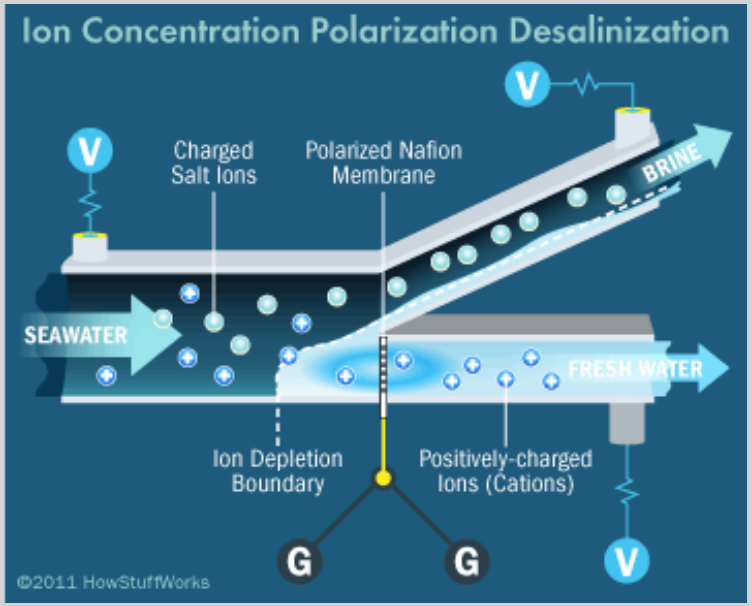
Solar thermal: Sun makes steam. Steam runs a turbine generator. No science needed, thank you.

- As cheap and efficient as photovoltaics.
- Can use natural gas as backup.
- Can use rocks underground to store heat so that generation continues after dark.

Desalination: Clean water from excess renewable electricity.

Nicely makes a mess of generation, storage, water, and grid.

Jebel Ali Desalination Staion, Dubai

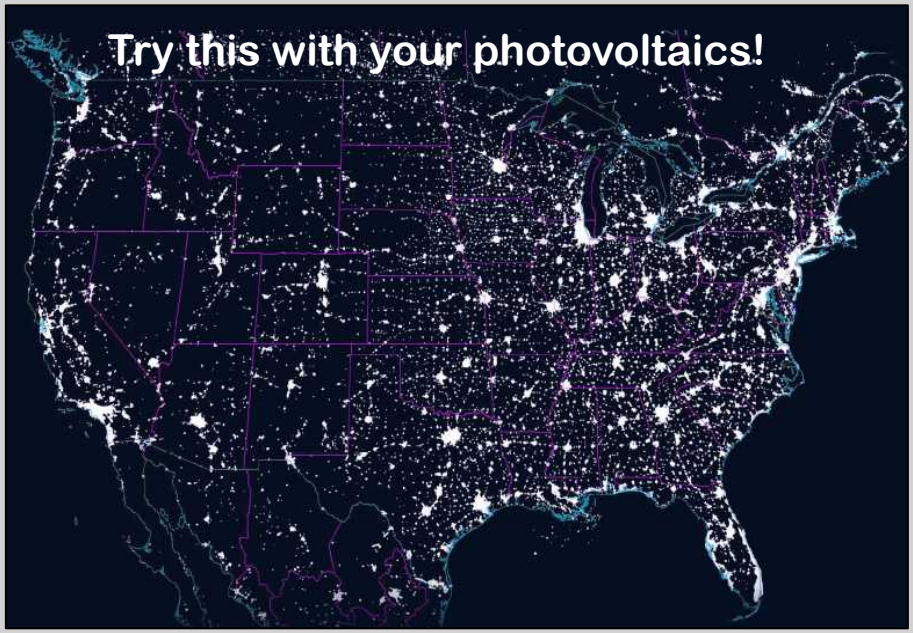


Los Alamos NATIONAL LABORATORY EST.1943

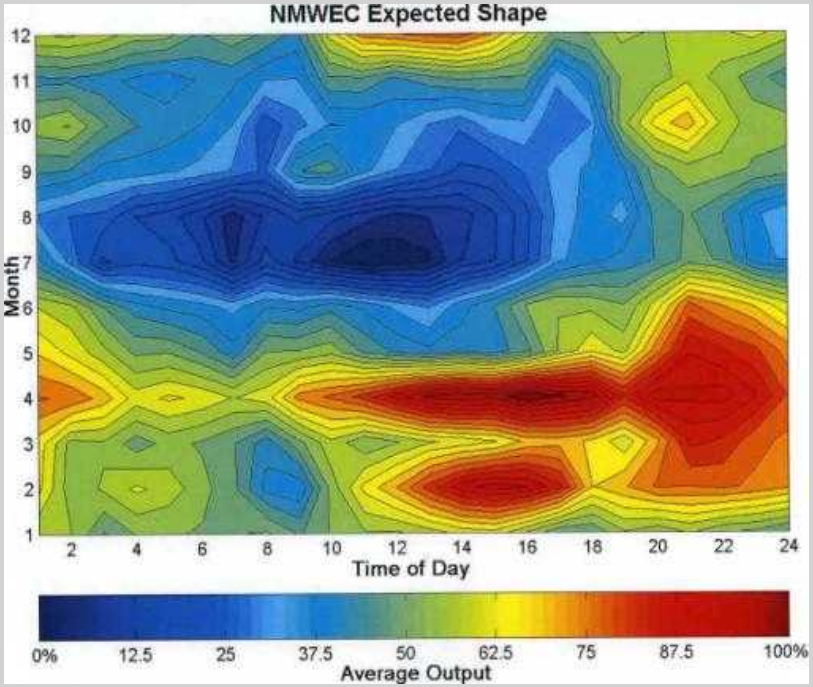
Electrical energy storage saves the world?

From: Department of Energy "Report of the Basic Energy Sciences Workshop for Electrical Energy Storage" (April, 2007):

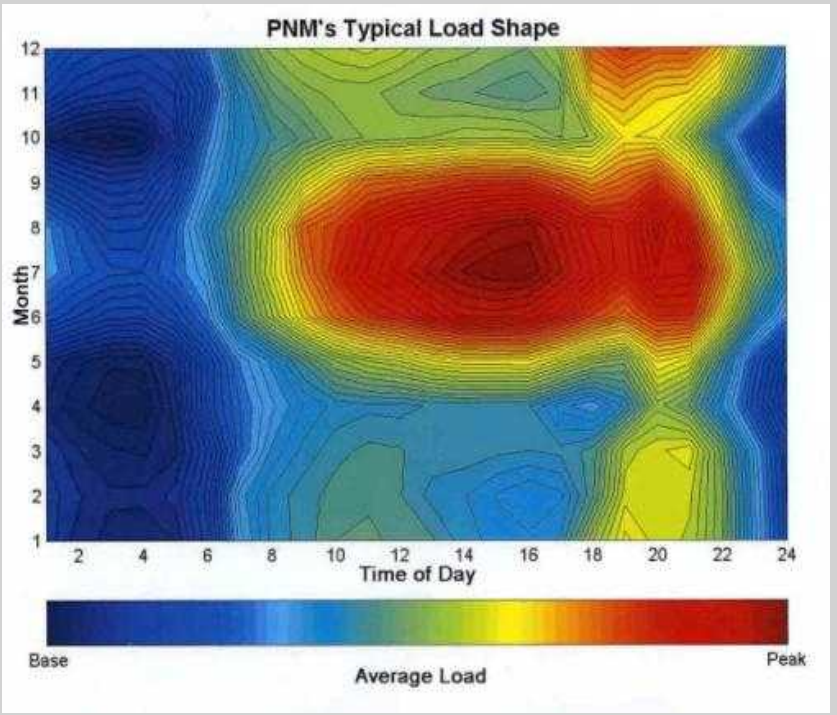
"***Revolutionary breakthroughs in electrical energy storage have been singled out as perhaps the most crucial need for this nation's secure energy future.***"



a) Renewable energy must be stored when available and recovered when needed



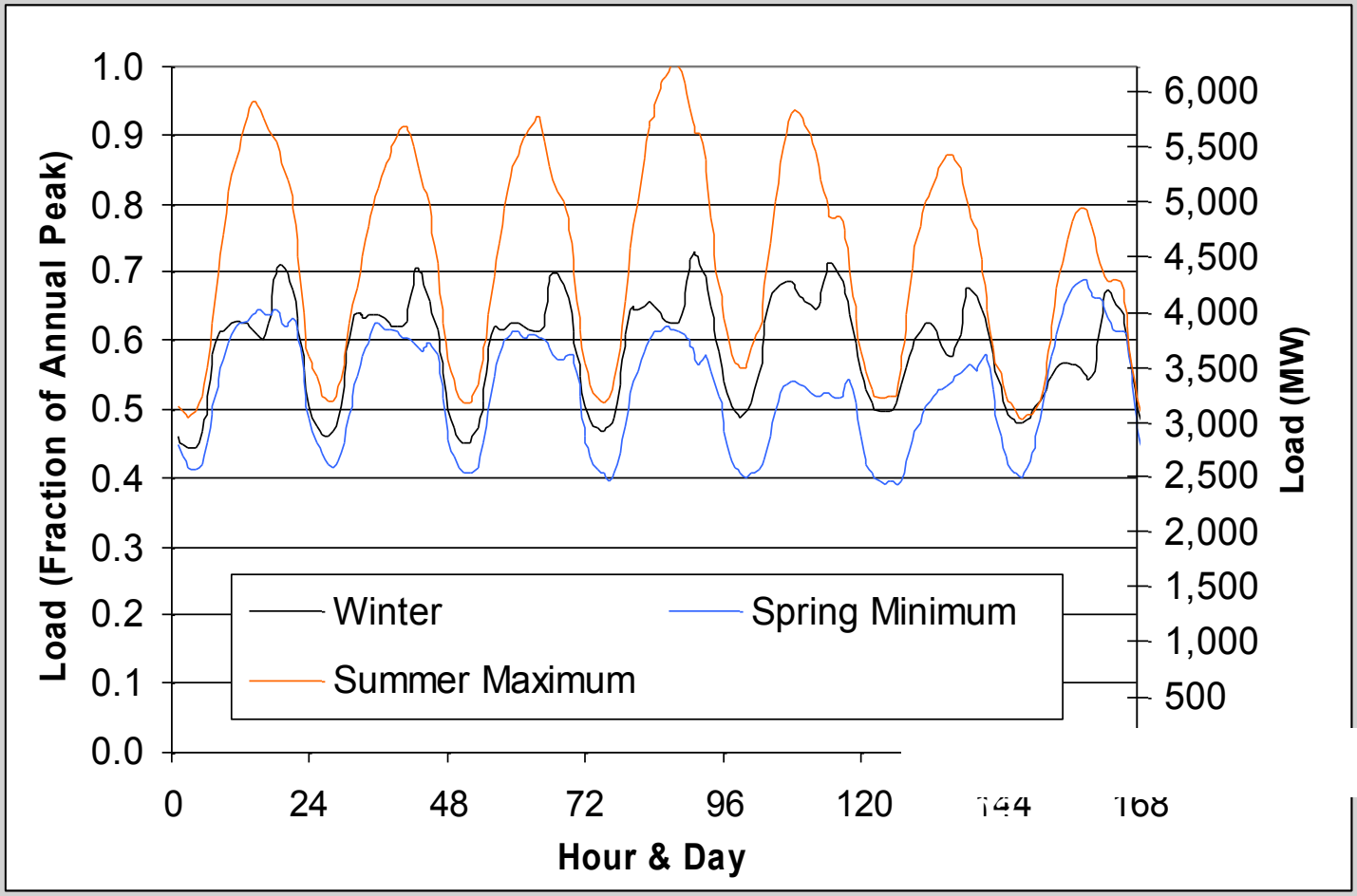
Renewable(wind) availability in New Mexico



Electrical energy use in New Mexico

Los Alamos NATIONAL LABORATORY EST.1943

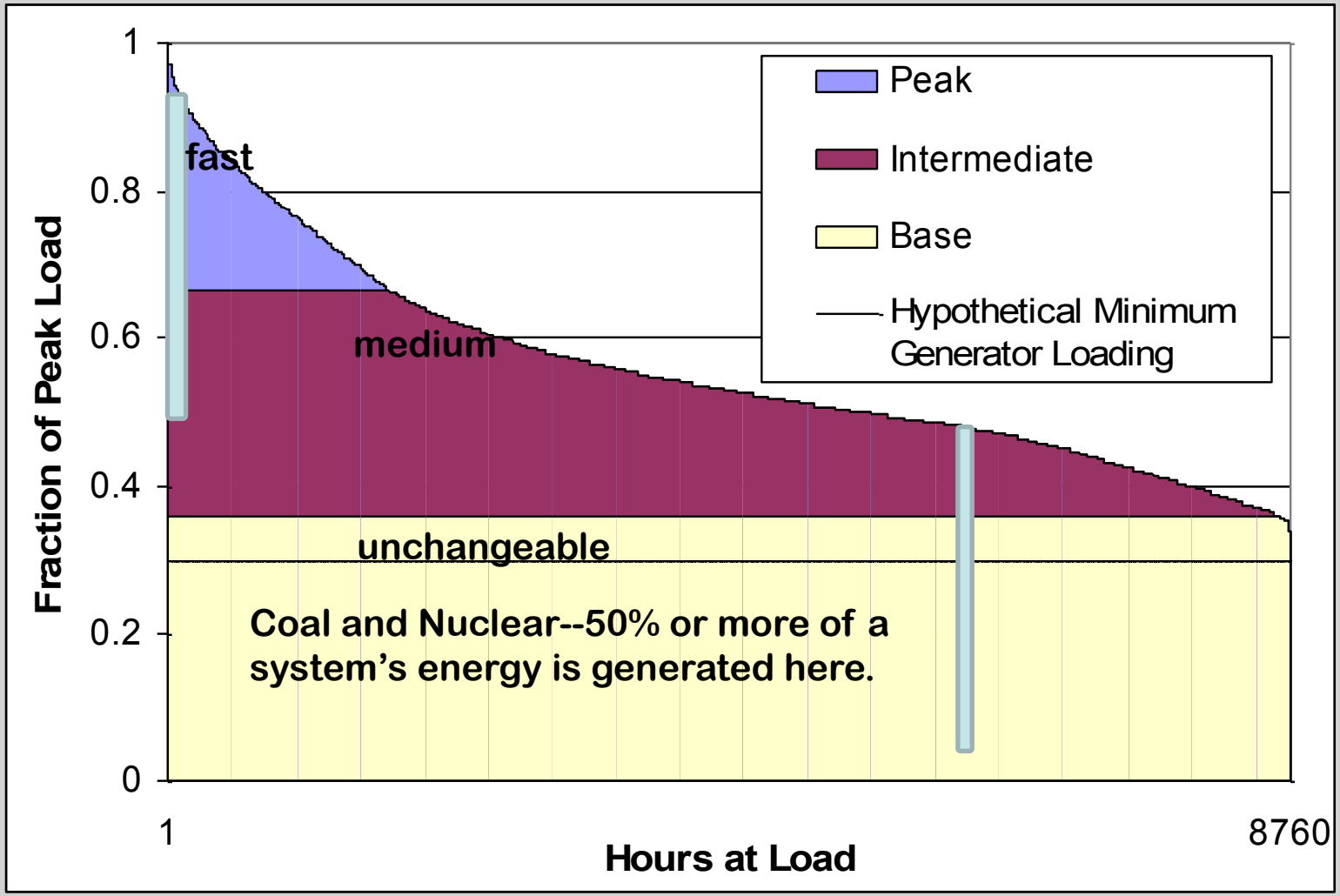
b) the loads are unpredictable
Courtesy Paul Denholm, NREL



How do we meet this demand with technologies that don't behave the way we would like them to

Los Alamos NATIONAL LABORATORY EST.1943

c) the utility grid has a hard lower bound on flexibility
Courtesy Paul Denholm, NREL



Los Alamos NATIONAL LABORATORY EST.1943

There are only two ways to store energy

- **Potential energy (PE)**

must be a field:
gravitational, chromodynamic, electroweak (electroweak is electric , magnetic , weak interaction below 100GeV).

- **Kinetic energy (KE)**

- **Storage technology in use today:**

Pumped hydro	**PE**
Flywheels	**KE**
Compressed air	**KE**
Magnetic	**PE+KE**
Thermal	**PE+KE**
Electricity-to-fuels	**PE**
Capacitors	**PE+KE**
Batteries	**PE**

- ***Capacitors, batteries, and electricity-to-fuels are identified as needing basic research***

Los Alamos NATIONAL LABORATORY EST.1943

Energy storage technology is varied

Expensive

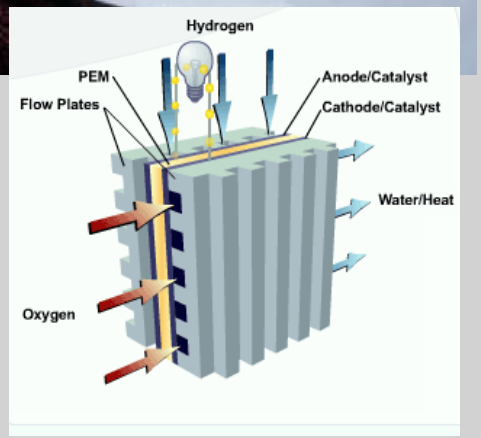
Cheap

battery

flywheel

capacitor

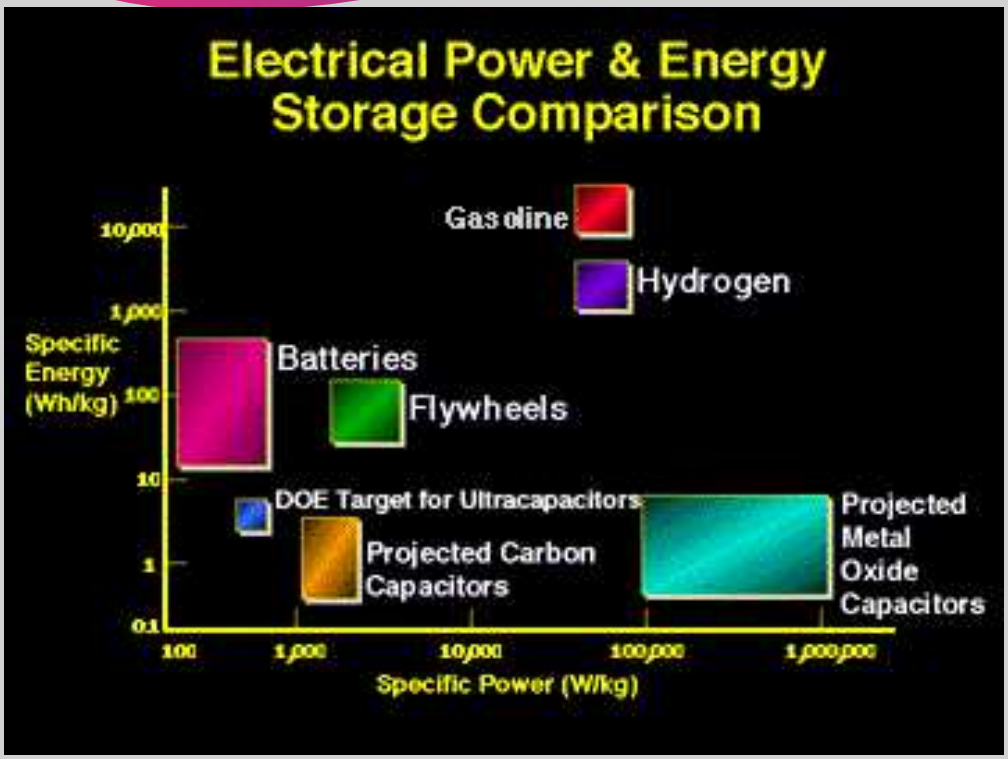
Pumped hydro



Fuel cell/electrolyzer

Los Alamos NATIONAL LABORATORY EST.1943

Energy storage numbers



There are a few hundred more axes:

- cost/joule
- size/joule
- loss/day
- utilization factor
- power/kg,.....

(1 kwh=3.6MJ = $0.10)

Fuels: 4-40 kwh/kg
(x Thermal Efficiency=
0.8 to 8 kwh/kg if burned).
This is very hard to ignore.
Especially in fuel cells.

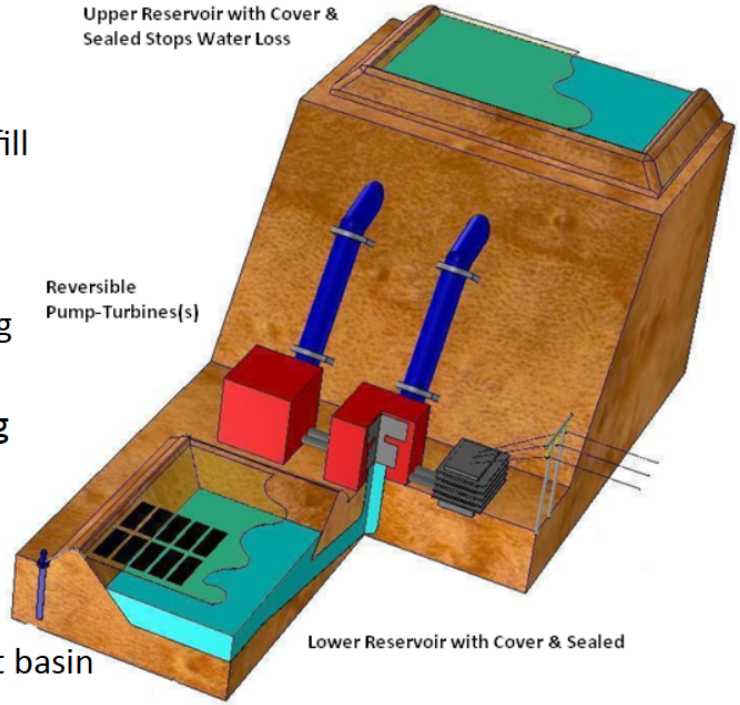
Gasoline:	12 kwh/kg
Zn-air battery:	0.45 kwh/kg
Li-ion battery :	0.15 kwh/kg
Supercapacitor:	0.02 kwh/kg
Antimatter	25,000,000,000 kwh/kg

Los Alamos NATIONAL LABORATORY EST.1943

Pumped hydroelectric energy storage in the desert actually makes sense

Modular Pumped Hydro(MPH) Details

- Design
  - Ring embankment, earth fill
  - Cover & line
  - Leakage recycled
  - Catch rainfall
  - Complimentary solar siting
- 30 to 300 m head
- 30 to 300 MW power rating
- < 12 hrs discharge
- Each reservoir
  - < 1000 acre-ft volume
  - < 10 acres surface area
  - Locate flat top mtn. w/flat basin



NM has crummy brackish water galore.

Los Alamos from the ski basin to town is 600M. There are elevation changes like this all over the US (but not Florida, sorry).

Instantaneous response to power demands.

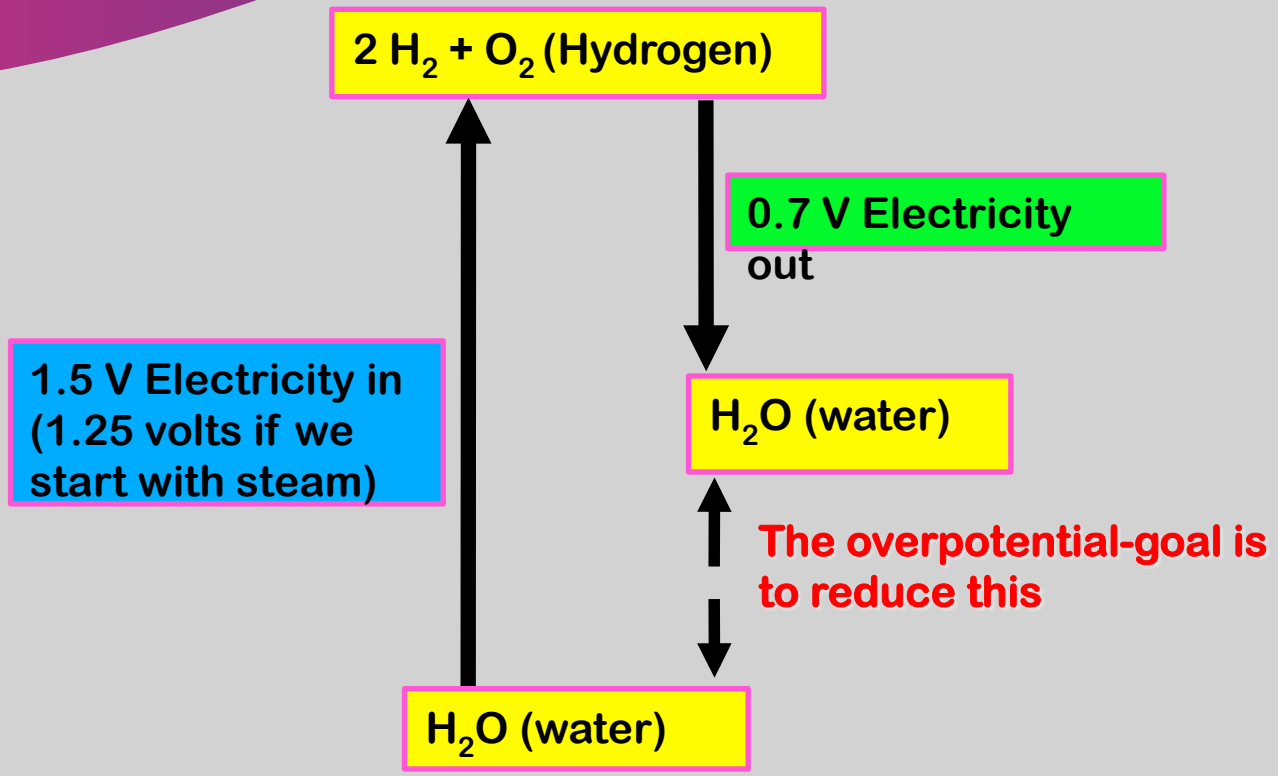
Costs like a gas turbine plant of similar output.

We can build this tomorrow.

But time-of-use legislation and tax credits are needed to jump-start.

Los Alamos NATIONAL LABORATORY EST.1943

Making chemicals from electricity--a *science* problem, *not* a technology problem.



Energy lost to splitting O_2	0.2V
Losses to Gas crossover	0.1 V
Water to steam	0.25 V
Other losses	0.25V

So 1.5 V in yields 0.7 Volts out

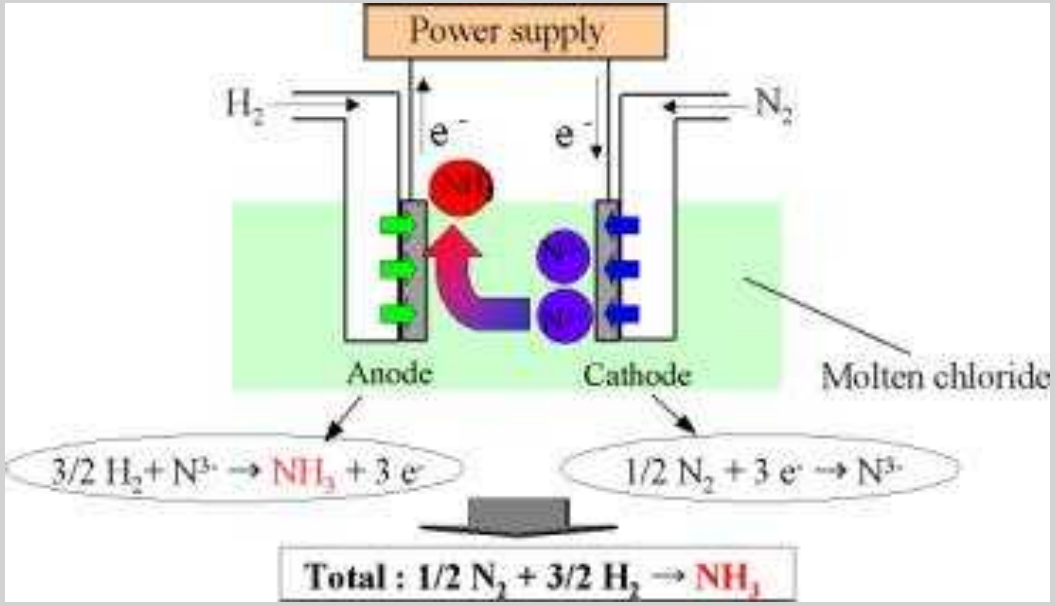
But it doesn't have to be that way. Electrochemical processes have no intrinsic limit on efficiency, like heat engines which are limited by Carnot.

Los Alamos NATIONAL LABORATORY EST.1943

Alternatives to hydrogen?

- Much innovative work has been done on direct conversion of bond energy to electricity (the fuel cell)

- but the reverse cycle (electrolysis) has not received as much attention.



$N_2 + 6H+ + 6e- \rightarrow 2NH_3$

Ammonia:

You can run it through a fuel cell to get electricity.

You can burn it in an engine (farmers used to use ammonia powered tractors).

It's the second most produced industrial chamical. Distribution in place.

No CO_2.

If we could make this efficient-game over, the planet is saved. Efficiency is only a few % today. But there is no scientific limit.

Los Alamos is working on this.

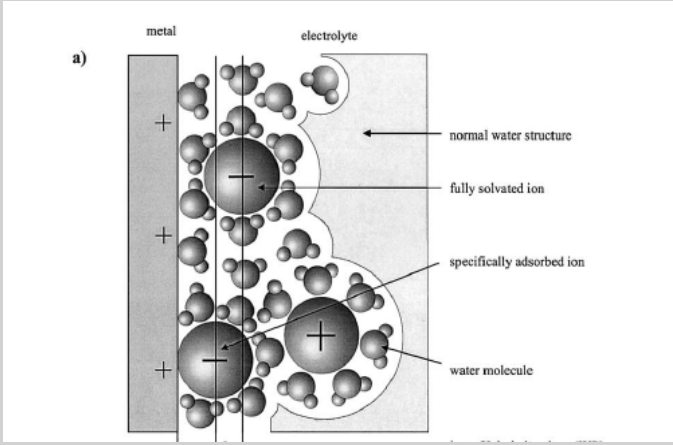
Los Alamos NATIONAL LABORATORY EST.1943

Sources of overpotentials are a combined physics and chemistry problem that must be solved for efficient electrochemical energy storage

The electronic density of states at the electrode-catalyst surface affects work functions and specific chemical activity.

The chemical potential (Fermi energy at finite temperature) measures the energy required to remove a particle from the system and is at the root of electrosynthesis.

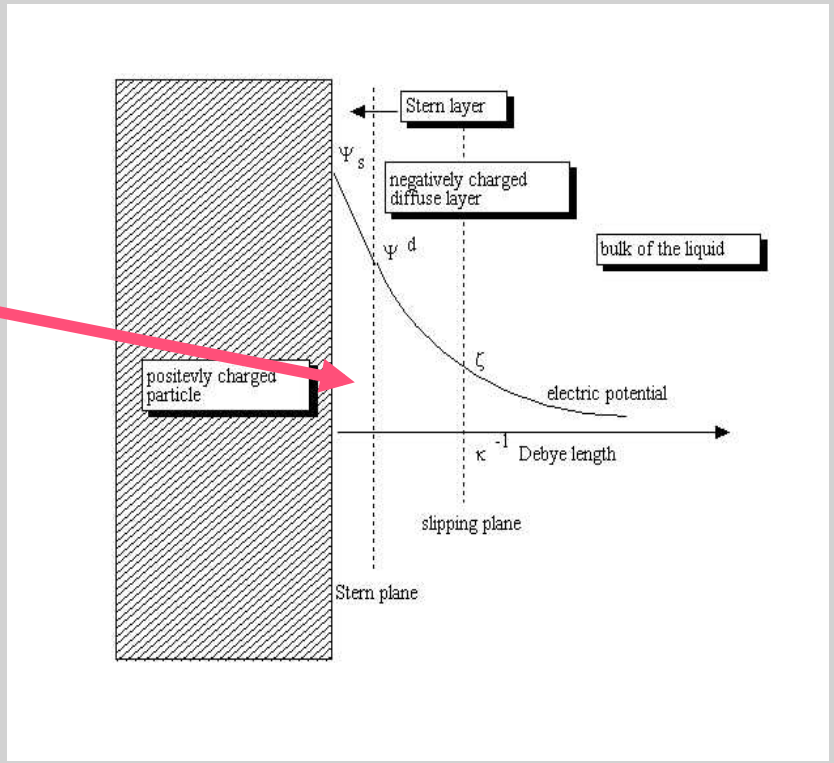
The electrical conductivity and susceptibility (dielectric constant) of the electrolyte changes the potentials required for dissociation.



Los Alamos NATIONAL LABORATORY EST.1943

Charged double layer is a result of screening

Electric field= $\frac{\text{voltage applied by electrochemist}}{\text{thickness of charged double layer}}$



- In an electrolyte-electrode assembly, electric fields of 3×10^9 V/m are easy.
- This is why electrochemistry works.

Los Alamos NATIONAL LABORATORY EST.1943

Debye length scales are complex

Debye screening length:

Charges in the ionic liquid with a voltage present pile up so that the local density is controlled by a Boltzmann distribution. Thermodynamics controls how things pile up:

$$N(z) = N_0 e^{-\frac{q\phi}{k_b T}}$$

Maxwell's equation defines local electric field and makes *really messy nonlinear equation* for the potential:

$$\nabla^2\phi(z) = \frac{qN_0\left(1-\exp\left(-\frac{q\phi}{k_b T}\right)\right)}{\varepsilon}$$

$$\lambda_D = \left[\frac{\varepsilon k_B T}{q^2 N_0}\right]^{\frac{1}{2}}$$

- **1000 nm in pure water—thick layer, low electric field, high *voltages* needed for chemistry.**
- **0.3 nm in 1M KCl-thin layer, extreme electric field, *voltages* approach thermodynamic limits.**

Los Alamos NATIONAL LABORATORY EST.1943

A rich science problem

The work function is connected to removing a charge from a metal.

Electrosynthetic energy storage involves moving ions away from the surface of a metal.

The energy depends on:

a) The density of states at the chemical potential. Determines the thickness of the screening charge layer and connects to the work function.

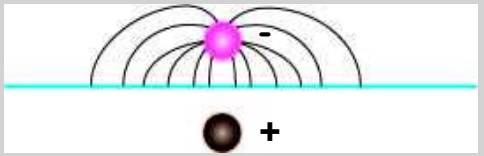
b)The electronic structure. Determines the chemical potential.

c)The electric field. Compresses the surface electron density and changes both the chemical potential and the surface charge density.

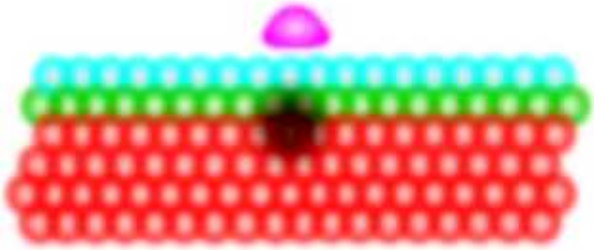
d) Reality: the electric field varies wildly.

It is very hard to determine the voltage between charge and plane.

All work functions the same



All work functions different



Los Alamos NATIONAL LABORATORY EST.1943

You don't actually have to *do* chemistry!

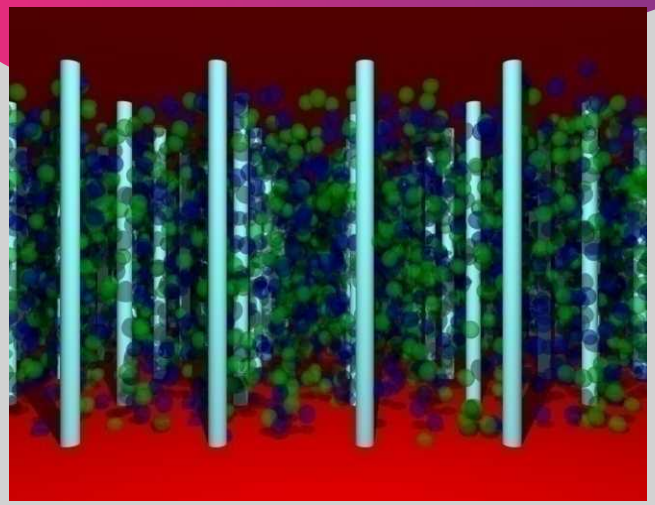
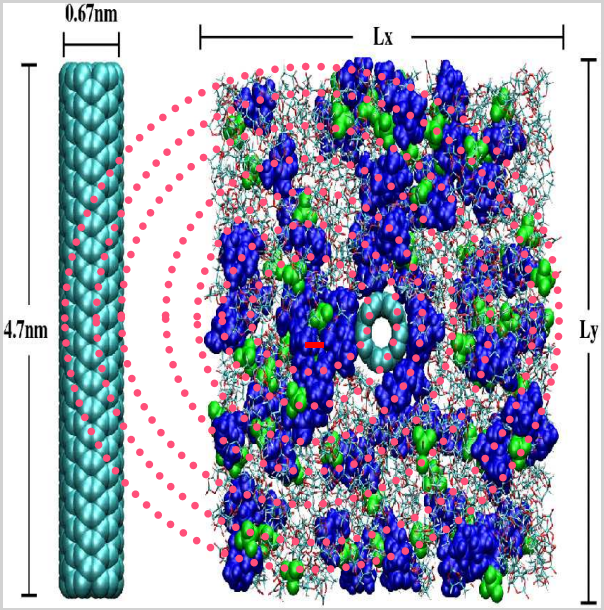
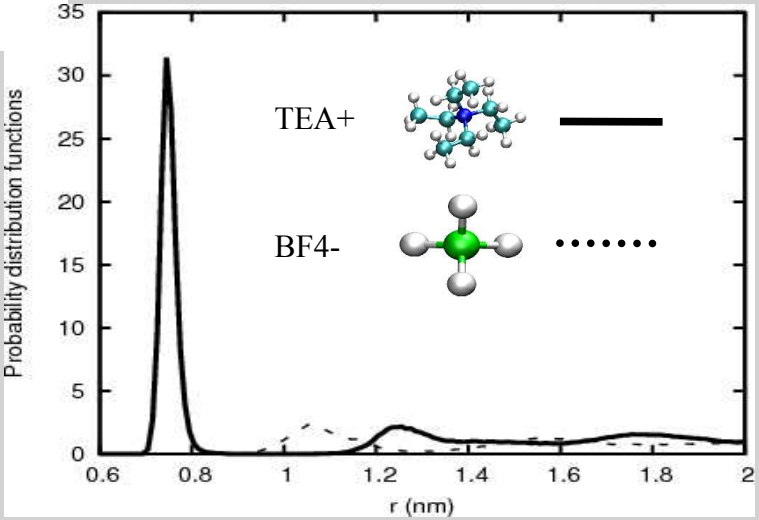


Figure : Coarse-grained model for nanotube forest with electrolyte





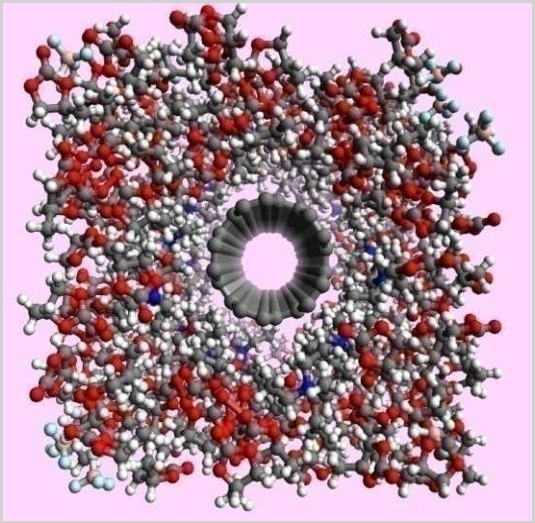


Figure : Snapshot of molecular dynamics simulation on a carbon nanotube with BF4-/TEA+/PC electrolyte

Los Alamos NATIONAL LABORATORY EST.1943

Summary

We have not succeeded in answering all of our questions. Indeed, we sometimes feel that we have not completely answered any of them. The answers we have found only served to raise a whole new set of questions. In some ways we feel that we are as confused as ever, but we think we are now confused on a higher level, and about more important things.

-Author unknown